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IMPACT OF COPPER SMELTER EMISSIONS ON TWO SUBALPINE ECOSYSTEMS NEAR ANACONDA, MONTANA

Preliminary Report by

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ABSTRACT

Preliminary analysis of data from this study in the mountains southwest of the Anaconda Copper Smelter, an industrial source of SO_2 and heavy metal particulate, reflects a complex pattern of pollutant impact. The differential effect of smelter emissions on plant life in the study area is best explained by the interrelationship of several factors including distance from the smelter, elevation, topography, and the position of the plant community on the landform. The data indicates that the ecological consequences of air quality degradation can be severe. Dramatic changes in plant community composition and serious reductions in vegetative cover were observed in the two forested ecosystems sampled. Tree coverage up to 66 percent was measured on control sites but dropped to less than 20 percent within 8 miles of the smelter. Shrub cover also varied directly with exposure to SO_2 concentration; near the smelter coverage was only 3 to 6 percent but was 50 to 66 percent at the remote sites. Living trees near the smelter had only one-half the needle retention of those on the distant sites. Up to 30 cm. of soil has eroded from the severely affected sites and normal microbial decomposition and nutrient cycling may be severely impaired. The results of this study provide the land manager with information regarding the ecological consequences of air quality degradation in forested mountainous areas.

1/ This evaluation was conducted under the direction of Dr. Clinton E. Carlson, Air Pollution Specialist, FI&DM, USDA, Forest Service, Northern Region, who is now at Intermountain Forest and Range Experiment Station, Missoula, Montana.

INTRODUCTION

The Anaconda Company has been smelting copper and emitting phytotoxic gases in the Deer Lodge Valley of western Montana for nearly 100 years. Initial smelting operations began in 1884, and the capacity of the plant was rapidly increased. By 1905 the Anaconda smelter was emitting more than 2,300 tons of sulfur dioxide and about 30 tons of arsenic trioxide each day, as well as considerable quantities of heavy metal particulates, mostly oxides of copper, zinc, cadmium, and lead (MacMillan 1973).

Although emissions have now been reduced to about 540 tons of SO_2 and 31 tons of arsenic and particulates a day (AQB 1978), the 585-foot stack currently disperses these toxic contaminants over larger areas.

Several researchers have investigated the effect of these emissions on plant life in the Anaconda area, but very little of this information has been published. Taskey (1972) and Hartman (1975) found soils in the vicinity of the smelter highly contaminated with copper, cadmium, zinc, and lead by the deposition and gradual accumulation of heavy metal particulate. Taskey's (1972) research indicates that soil contamination to toxic levels is partially responsible for the scarcity of conifer regeneration in the Mill Creek drainage southwest of Anaconda. Hartman (1975) found a strong inverse relationship between the concentration of metals in Anaconda soils and the diversity and abundance of soil microfungi, organisms which play an important role in nutrient cycling.

A recent study by Olson-Elliott and Associates, environmental consultants for the Anaconda Copper Company, documents the extent of pollutant induced ecological change in different radial directions from Anaconda. However, this information is unavailable because the Anaconda Copper Company has not released this report for general review.

There is a lack of published information regarding the consequences of air quality degradation on forested mountain ecosystems in the Northern Region. The Federal land manager requires this information in a readily accessible form to assess the importance of air quality in areas where protection of biological systems is a management policy. In Region 1, the Forest Service manages approximately 4.2 million acres of Wilderness area, 7.8 million acres of RARE II area, and 1.2 million acres of Primitive area for preservation in a pristine condition.

In addition to management goals and guidelines, the 1977 Amendments to the Clean Air Act require the Federal land manager (Forest Service) to take affirmative action in air quality issues. The Amendments designate all Wilderness areas over 5,000 acres and National Parks exceeding 6,000 acres as of August 7, 1977, to Class I air quality. This means that virtually no increase in existing, or baseline, pollutant concentrations will be allowed in these areas. The Federal land manager is responsible for actively protecting the Class I status of lands they manage and must review proposed major emitting facilities to determine their effect on these lands. Additionally, the Amendments direct the Federal land

manager to review and consider for redesignation to Class I lands such as new Wilderness areas and previously established Primitive areas, where air quality related values are important attributes of the area.

The forested area around the Anaconda Copper Smelter in Anaconda, Montana, is an ideal field laboratory in which to evaluate the potential cumulative effect of long-term exposure to SO_2 and particulate pollution on a wilderness-like mountain ecosystem. This project was initiated to investigate, document, and if possible, quantify the possible SO_2 and heavy metal impacts on two subalpine plant communities which have an extensive distribution in Montana. This information will be invaluable to the Federal land manager responsible for assessing the significance of air quality degradation relative to forested ecosystems.

DESCRIPTION OF STUDY AREA

The Anaconda-Pintler Mountain Range, with peaks rising to 10,600 feet elevation and forming part of the Continental Divide, lies directly southwest of the smelter (figure 1). Since data from the Anaconda Copper Company's C-Hill monitoring station showed substantial wind frequencies in the southwest direction during the growing season, this chain of mountains was selected as the area of study.

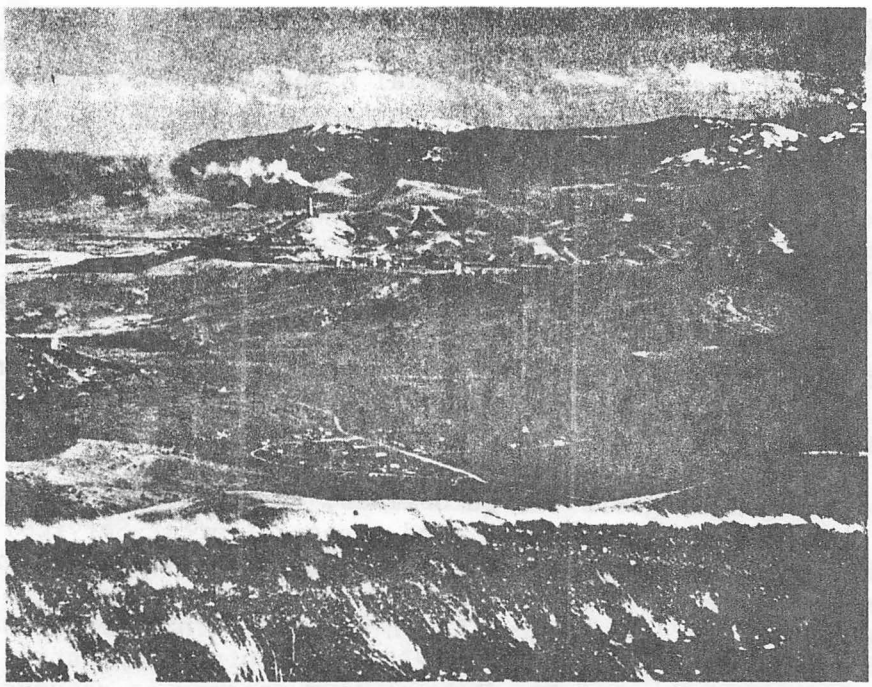

Figure 1.--Sulfur dioxide and heavy metals emitted by the Anaconda Copper Smelter have caused extensive irreparable ecological damage to conifer forests. The smokestack is about 130 m. high. Much of the treeless area was forested prior to smelter operation.

The Anaconda-Pintler Range is a narrow chain of mountains approximately 15 to 30 air miles in width and extends for about 40 miles from Anaconda in a northeast-southwest orientation. The mountains were formed by the uplift of the Boulder Batholith at the beginning of the Tertiary or end of the Cretaceous period. This granitic intrusion displaced the Precambrian and Paleozoic sedimentary rocks and forms a large proportion of the parent material in the alpine and upper subalpine areas of the range. Metamorphosed sedimentary rocks, predominantly gneiss and quartzite, form most of the parent material for the adjacent lower slopes. Repeated glaciation during the Pleistocene era, however, carved out mountain canyons and valleys and created areas of glacial drift, outwash and moraine parent material. Several foothills within the study area are beyond the area of glaciation and are formed from Tertiary sedimentary rocks metamorphosed to quartzite. Volcanic activity during the Tertiary in the adjacent Pioneer Range additionally influenced portions of this foothill area by depositing layers of igneous rock (Dutton 1978).

Although parent material varies throughout the study area because of the complex geological processes which create mountains, the vegetation generally follows the regional elevational and exposure patterns described in "Forest Habitat Types of Montana" by Pfister et al. (1977).

METHODS

Description of Plant Communities Sampled

Two forest habitat types (Pfister et al. 1977) were selected and comprised the sampling strata within the study area. Basically, random sampling was utilized within this stratification. Eleven study plots were established in the two strata, five in the *Abies lasiocarpa/Vaccinium scoparium* habitat type (h.t.) and six in the *Abies lasiocarpa - Pinus albicaulis/Vaccinium scoparium* h.t. at a distance and elevational gradient from the smelter (figure 2). In addition to using habitat types (a classification of physical environments based upon potential climax plant communities (Pfister et al. 1977), environmental variables such as topography, elevation, aspect, and percent slope were held reasonably constant.

Abies lasiocarpa/Vaccinium scoparium h.t.:

The Continental Divide splits the study area and influences plant community structure by providing a barrier to the milder, more moist, Pacific climate. Pfister et al. (1977) noted that near the Divide the *Abies lasiocarpa/Xerophyllum tenax* h.t. in the *Vaccinium scoparium* phase (ABLA/XETE-VASC) is transitional to the *Abies lasiocarpa/Vaccinium scoparium* h.t. (ABLA/VASC) generally found east of the Divide. Within the study area these two habitat types can be considered comparable because the sampling locations are a maximum of 40 miles from each other and they are treated as one for the purpose of this study.

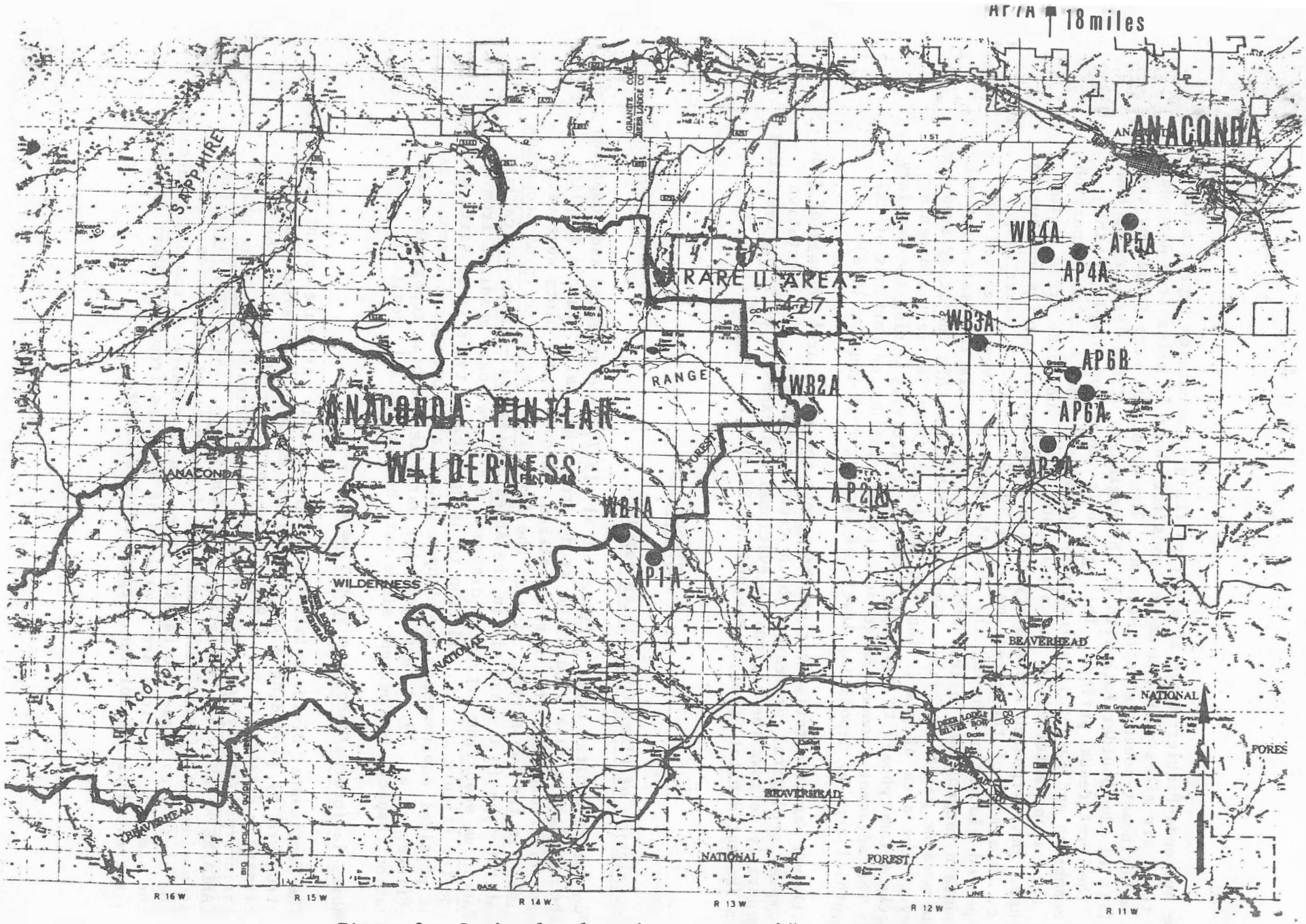

Figure 2.--Study plot locations. Scale ½" = 1 mile.

Five of the study plots were located in this combination of habitat types. One sampling site is located northwest of the smelter in the Flint Creek Range west of the Divide. Four sampling sites are located southwest of the smelter in the Anaconda-Pintler Mountains. Of these four transects, one is west of the Continental Divide, one is on the Divide, and two are east of the Divide. All five study plots are located on prominent ridgetops with an east aspect at 6,900 to 7,200 feet elevation and have a 10 to 20 percent slope. These two habitat types are extensively distributed in Montana and, considered separately, represent a substantial portion of Montana's forested area. The ABLA/XETE h.t., generally found between 5,200 and 7,000 feet elevation, is one of the most common habitat types of the Abies lasiocarpa series west of the Divide (Pfister et al. 1977). The ABLA/VASC h.t., having an elevational range between 6,000 and 7,500 feet, is one of the most abundant forest habitat types near and east of the Continental Divide in Montana (Pfister et al. 1977).

Abies lasiocarpa - Pinus albicaulis/Vaccinium scoparium h.t.:

Six study plots were established in this plant community type (ABLA-PIAL/VASC) to determine if an elevational as well as distance gradient of smelter impact could be detected. Even though it is the most widely distributed at the higher elevations in Montana east of the Continental Divide (Pfister et al. 1977), this habitat type also occurs at lower elevation sites having severe climatic or edaphic conditions. Four of the sampling locations are located further upslope, at 8,000 to 8,100 feet, from those in the ABLA/VASC h.t. sample sites. The other two study plots have an elevation of about 7,000 feet. All of these sites are located on prominent ridgetops with east aspect and a 15 to 20 percent slope.

Subplot Sampling

At each site two parallel transects 100 meters in length were established along the top of and parallel to the ridge. Forty 10- by 10-meter subplots were located along these transects. The ecological characteristics of each site were sampled in 10 randomly selected subplots of each transect 2/ (figure 3). The measurements at each of these 10 subplots included:

1. Identification of all plant taxa present at least to genus.

2. Direct measurement of height and visual estimation of percent cover of each species.

2/ Complete sampling as described was accomplished for the lower elevation plant communities. However, the relative inaccessibility of the sites at 8,000 feet necessitated a smaller sample size and no soil data was collected.

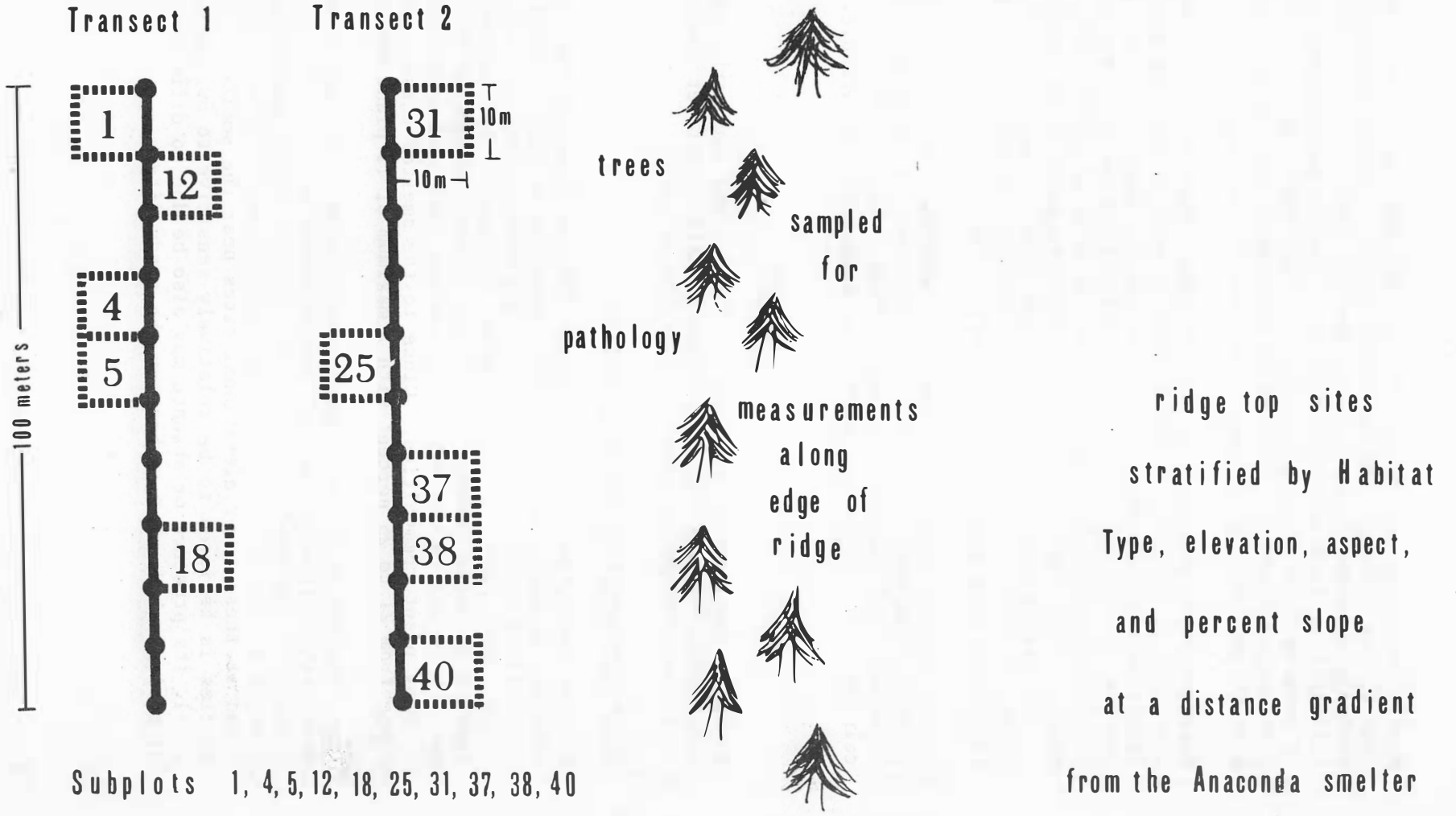

Figure 3.--Schematic of sampling design.

Needle pathology was evaluated and included insect and fungal-caused injury, tip necrosis, and chlorotic mottle. Evaluations were made on 100 randomly selected Pinus contorta needles from the 1977, 1976, 1975, and 1974 foliage from each tree sampled. Similar measurements were made on 50 needles from Pinus albicaulis for the same 4 years of foliage. The percentage of needles affected by each agent and a visual estimate of the percent necrosis or chlorosis related to each agent were recorded.

Representative specimens of the different types of injury were saved for histological analysis. These samples were killed and fixed in FAA (formalin-aceto-alcohol) using a vacuum to remove air from the tissue and replace it with the FAA. The paraffin technique will be used for sectioning the samples which will then be stained in Feulgen's fast green method. Histological analysis of these slides will be used to determine if the needle pathology has resulted from a climatic stress such as frost, or was caused by insect or disease activity, or is a result of fumigation by a phytotoxic gas (Carlson 1978).

Random samples of whole needles with sheaths from 5 years foliage, 1977 to 1973, from each tree were saved for chemical analysis. These analyses included total sulphur, sodium, nitrogen, lead, copper, zinc, cadmium, calcium, iron, potassium, magnesium, manganese, and arsenic.

RESULTS

Although the chemical analyses of the foliage and soils and in-depth statistical analysis of the ecological data is not yet complete, preliminary observations are given in this status report.

Abies lasiocarpa/Vaccinium scoparium h.t.:

Percent vegetative cover and plant species diversity may indicate the substantial affect of the smelter emissions on plant communities in this part of the study area (table 1). The average percent total vegetative cover ranges from 125 to 150 percent represented by a maximum of 33 plant species at sites greater than 14 air miles from the smelter. This high percent is due to the overlap of various layers of undergrowth inherent in many plant communities. Close to the smelter these coverage values range from 21 to 25 percent with a maximum of 18 plant species.

Tree coverage on these sites varies from 58 to 66 percent on the sites more distant from the smelter but decreases to 0.1 to 20.2 percent within 8 miles of the smelter. One tree species, Abies lasiocarpa, which is present at all of the sites with high values of tree coverage, is not found at these lower elevational sites near the smelter. Although this species is believed to be relatively sensitive to SO_2 pollution (Mason 1915), its presence or absence may also be due to differences in the stage of ecological succession between the study sites.

Table 1

Sites Sampled in the ABLA/VASC and ABLA/XETE-VASC h.t.

Site	AP1A	AP2A	AP7A	AP4A	AP6B
Habitat Type	ABLA-VASC	ABLA-XETE-VASC	ABLA-XETE-VASC	ABLA-VASC	ABLA-VASC
Distance and Direction From Anaconda	21 mi. SW	14.5 mi. SW	18 mi. SW	4.4 mi. SW	7.2 mi. SW
Elevation	7100 ft.	6900 ft.	7200 ft.	6900 ft.	6900 ft.
Aspect	80° NE	100° ESE	90° E	90° E	75° E
% Slope	12%	10%	15%	20%	10%
Soil Parent Material	Granite	Granite	Granite	Gneiss	Rhyolite, Tuft, Quartzite
Sulfation Rate in mg $SO_3/100\ cm^2/day$	No data	.19	No data	.48	1.48
Total Tree Cover	58.0%	61.6%	66.2%	20.2%	.1%
# Tree Species	3	4	4	2	1
Total % Shrub Cover	49.8%	66.3%	65.3%	3.4%	6.1%
# Shrub Species	6	5	6	9	3
Total % Grass Cover	13.0%	8.4%	.6%	.6%	15.8%
# Grass Species	1	2	1	3	6
Total % Herbaceous Cover	1.6%	11.5%	20.8%	.8%	4.8%
# Herbaceous Species	7	17	8	3	6
Total % Lower Plant Cover (Lichens, Mosses, Fungi)	6.1%	6.5%	2.4%	.1%	0%
Total % Vegetated Cover	128.2%	150.6%	155.3%	25.3%	26.8%
Total # Plant Species	21	33	24	18	16
Total % Nonvegetated	14.2%	4.3%	7.7%	78.3%	73.6%
Lodgepole Pine - Age	60-80 yrs.	80-100 yrs.	100+ yrs.	0-55 yrs.	0-35 yrs.
Height	56.4 ft.	71.1 ft.	71.8 ft.	37.37 ft.	21.1 ft.
DBH	7.65 in.	8.48 in.	9.23 in.	5.92 in.	6.47 in.
Basal Area	160	208	226	30	no B.A.
% Live Crown	47.0%	46.6%	36.8%	96.3%	93.0%
% Cover	57.0%	61.0%	54.0%	19.0%	.7%

The amount of shrub coverage may also be influenced by pollution. The control plots have coverage values ranging from approximately 50 to 66 percent. Nearer to the smelter these values vary from 3 to 6 percent cover.

There are no apparent pollution-related trends in total grass coverage values. However, grass species diversity increases closer to the smelter, especially the bunch grasses. Calamagrostis rubescens, an indicator plant species for the habitat type, decreases closer to the smelter, but the absence of this grass on the control plot west of the Continental Divide may indicate that the Divide influences its distribution in the study areas.

There are no clear pollution related trends with the forbs, although annual plant species, such as goldenrod and fireweed, predominate close to the smelter. The Continental Divide also may influence the diversity of forb species. On the control plot nearest to the Divide, 17 different annual and perennial forbs are found. A maximum of eight forbs are found on the other sites.

Lichens, mosses, liverworts, and mushrooms consistently provide from 2.5 to 6 percent of the ground cover in the control plots but are almost totally absent in the sampled area within 10 miles of the smelter. Only a few necrotic mosses and one mushroom were found in the impacted area. Lichens, lower plants which play an important role in breaking down rock to soil and preventing erosion by providing protective ground cover, are very sensitive to air pollution. Although six or seven different species of rock and ground lichens were found at all of the sites distant from the smelter, no living lichens were found on the plots close to the smelter.

The amount of earth surface on sites near the smelter having no protective vegetation averages from 70 to 78 percent. A maximum of 14 percent was found on the sites more distant from Anaconda. This lack of vegetation has resulted in accelerated erosion, and loss of topsoil has been substantial. A loss of 15 to 30 cm. of soil at the Continental Divide site, 7.2 miles from the smelter is evidenced by pedestaled bunch grasses and airborne roots of stumps (figure 4).

Absence of the litter layer is also unique to the sites close to the smelter, although fairly deep layers (8 to 12 cm.) of nondecomposed needles can be found under the conifers having extensive basal branching. This buildup of needles and the absence of a decomposed needle-litter layer suggests the decomposer micro and/or macroorganisms of the ecosystem may not be functioning normally. A disruption in nutrient flow through the system, combined with the loss of soil nutrients through erosion, would be an extremely serious ecological consequence of past and present smelter emissions.

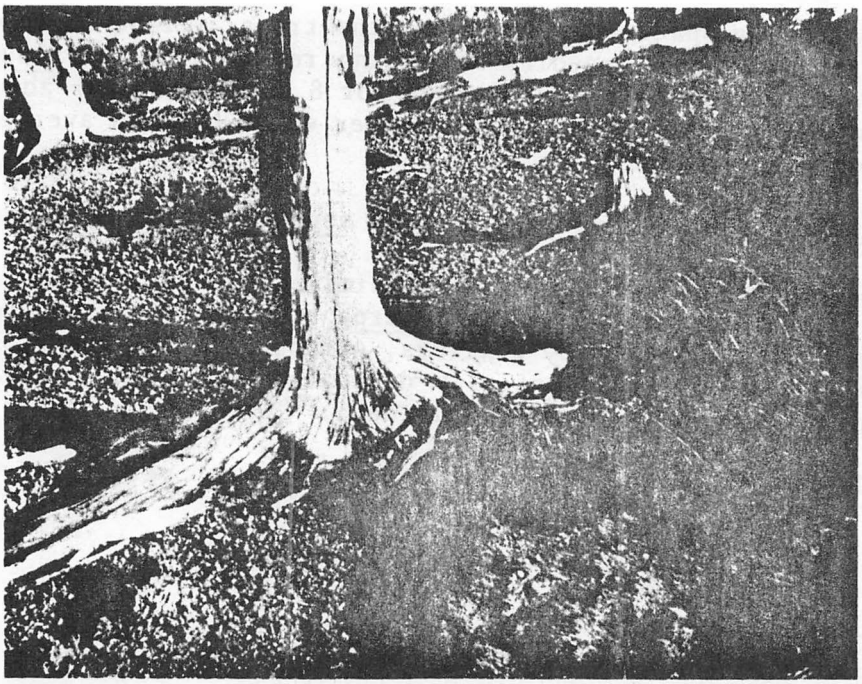

Figure 4.--Extensive soil erosion is occurring because most of the vegetative ground cover has been eliminated by the smelter pollution. Note the exposed roots of the stump and the pedestaled bunch grasses. Nearly 30 cm. of soil has been lost.

The age of the conifers and the vigor of the trees as measured by percent live crown and needle retention data additionally suggest smelter influence. The trees on the most impacted sites are distributed into all age classes with a maximum age of about 55 years. This all-age structure is very unusual as Pinus contorta stands in these habitat types are usually even-aged (Arno 1978). The maximum age of these Pinus contorta may correspond to the installation of pollution control measures in the 1920's. At a distance from the smelter it was very difficult to find young Pinus contorta stands having the criteria (similar aspect, elevation, etc.) necessary for comparison. Conversely, close to the smelter it was impossible to find older stands of this species. Therefore, the control stands are somewhat older, and they have an even-age structure.

The stand vigor as measured by percent live crown varied with distance from the smelter but is a reflection of tree competition and the age of a stand. The trees at the sites nearer to the smelter are open grown, generally have live branches to their base, and average 90 to 100 percent live crown. The tree stands on the control sites have a closed canopy,

competition for growing space is strong, and the trees average 30 to 45 percent live crown. However, needles are being retained on the Pinus contorta trees sampled at the control sites for 8 to 13 years or about twice as long as on trees closer to the smelter which have an average retention time of 4 to 7 years.

Abies lasicocarpa - Pinus albicaulis/Vaccinium scoparium h.t.:

The data from this habitat type reflect very similar trends in the ecological parameters measured in the Abies lasiocarpa type previously described. Vegetative ground cover provided by conifers, shrubs, and the lower plants, lichens, mosses, and fungi, substantially decrease within the area of smelter influence. Table 2 summarizes this data.

Data on soil chemistry, pathology, and histology are not yet analyzed.

DISCUSSION AND CONCLUSIONS

The field work indicates that smelter emissions have seriously altered communities in the Anaconda-Pintler Mountains. Ecological succession appears to have been interrupted and retrogression, or reverse ecological succession, may have occurred on more than half of the study plots. Although wildfire is a common occurrence in these habitat types and timber harvest has affected the study area, the patterns, extent, and type of ecological damage observed is most adequately explained by the past and present heavy fumigations of phytotoxic gases emanating from the smelter.

The mountain topography combined with wind dispersal patterns (van Ee 1978) result in a complex mosaic of pollution impact in the Anaconda area. Concentrations of air pollutants, therefore their toxicity, generally decrease with distance from the industrial source due to the mixing of the effluent with local winds (Padmanabhamurty 1975). However, topography may strongly influence patterns of pollutant dispersal (Moroz 1969). The mountain topography southwest of Anaconda may protect some areas near the smelter from plume strike, while other areas much further away may be consistently fumigated by wind-borne pollutants funneled up mountain valleys. An additional influence of mountain topography results in temperature inversions which occur when cold air in the valley is trapped below a blanket of warmer air aloft. This stagnation of air can result in a buildup of air pollutants to toxic levels within the inversion layer. The data from this study reflect these topographical and elevational influences. Pollution damage in the Anaconda-Pintler Mountains does not follow a straight line decrease with distance from the smelter. The Continental Divide site, which is 7.2 miles from the smelter and is in the ABLA/VASC h.t., is vulnerable to direct plume strike (van Ee 1978) and has been impacted much more than the Mt. Haggin site located 4.4 miles from the smelter stack but apparently protected by C-Hill.

The data from the ABLA-PIAL/VASC h.t. indicate a declining gradient of pollution impact with increase in elevation. Two of the four upper elevation sites sampled at 8,000 feet have evidence of smelter influence but the two sampling locations at 7,000 feet are degraded to a much greater extent. One of these depauperate lower elevation sites, Knob Hill, is fairly distant at 10 air miles from the smelter east of the Continental Divide. Thermal inversions combined with landform configuration may explain the differences between these sampling locations.

In general, the data from both habitat types indicate that clean air may be an important factor in protecting the ecological integrity of certain plant communities in Region 1.

Table 2

Sites Sampled in the ABLA-PIAL/VASC h.t.

Site	WB1A	WB2A	WB3A	WB4A	AP3A	AP5A
Habitat Type	ABLA-PIAL/ VASC	ABLA-PIAL/ VASC	ABLA-PIAL/ VASC	ABLA-PIAL/ VASC	ABLA-PIAL/ VASC	ABLA-PIAL/ VASC
Distance and Direction From Anaconda	21.1 mi. SW	14.3 mi. SW	8.6 mi. SW	4.5 mi. SW	10 mi. SW	2.8 mi. SW
Elevation	8050 ft.	8000 ft.	8050 ft.	8000 ft.	6950 ft.	7050 ft.
Aspect	80° NE	105° E	90° E	90° E	90° E	80° E
% Slope	15%	15%	20%	20%	20%	15%
Soil Parent Material	Granite	Granite	Granite	Gneiss	Quartzite	Quartzite
No Sulfation Rate Data Available	At This Time					
Total % Tree Cover	52.2%	78.0%	38.7%	22.0%	2.9%	.05%
# Tree Species	4	4	2	3	2	1
Total % Shrub Cover	49.5%	43.5%	40.0%	15.7%	8.1%	11.05%
# Shrub Species	3	2	1	1	6	7
Total % Grass Cover	1.7%	.5%	7.0%	1.2%	3.4%	.85%
# Grass Species	3	1	3	3	5	3
Total % Herb Cover	.3%	.17%	13.0%	.2%	.6%	1.1%
# Herb Species	1	1	7	1	4	4
Total % Lower Plant Cover (Lichens, Moss Fungi)	19.3%	4.7%	0	0	0	.15%
Total % Vegetated Cover	123.0%	126.9%	98.7%	39.0%	14.9%	13.3%
Total # Plant Species	14	11	13	8	17	16
Total % Non-vegetated	16.3%	40%	20%	80.8%	85.2%	87.7%
Whitebark Pine - Age	60-70 yrs.	80-100 yrs.	40-60 yrs.	100+ yrs.	0-30 yrs.	0-10 yrs.
Height	39 ft.	49.3 ft.	29.2 ft.	43 ft.	7.8 ft.	2 ft.
DBH	6.73 in.	8.86 in.	6.48 in.	10.0 in.	1.6 in.	1 in.
Basal Area	108	67	60	48.5	0	0
% Live Crown	78.3%	86.3%	88.0%	66.3%	90%	100%
% Cover	31.7%	28.3%	36.7%	20.0%	1.7%	.05%

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